AMERICAN RECOMMENDED PRACTICE

of

INDUSTRIAL LIGHTING

Approved March 17, 1942

by

American Standards Association

Prepared under the sponsorship of

ILLUMINATING ENGINEERING SOCIETY

51 Madison Avenue, New York, N. Y.

Price 25 Cents

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FOREWORD

American Recommended Practice of Industrial Lighting is a revision of the Code of Lighting: Factories, Mills and Other Work Places developed under the rules of procedure of the American Standards Association, and under the administrative leadership of the Illuminating Engineering Society.

Illuminating Engineering Society

The Illuminating Engineering Society was organized in 1906 for the advancement of the theory and practice of illuminating engineering and the dissemination of knowledge relating thereto. The Society has now about 3300 members who are interested in the subject of lighting from various standpoints: engineering, economic, hygienic, aesthetic.

The Society has no affiliation with any commercial organization. Anyone interested in its objects may become a member.

In this revision the sponsor organization, the Illuminating Engineering Society, has had the active collaboration of a Sectional Committee, organized under the rules and procedure of the American Standards Association, and made up of the following representatives officially designated by the respective societies and organizations.

Sponsor: Illuminating Engineering Society
Officers: Professor H. B. Dates, *Chairman*
Willard C. Brown, *Secretary*

Organization Represented	*Name and Business Affiliation*	*Classification (See Summary)*
The American Institute of Architects.	E. Jerome O'Connor, 101 Park Avenue, New York, New York.	E
American Institute of Electrical Engineers.	I. A. Yost, Westinghouse Electric & Mfg. Company, 1216 West 58th Street, Cleveland, Ohio.	E

CANADIAN GENERAL ELECTRIC COMPANY
LIMITED
HEAD OFFICE TORONTO, ONT

June 10, 1942.

Mr. Ernest Cormier,
Architect,
2039 Mansfield St.,
Montreal, Que.

Dear Sir,

"Recommended Practice of Industrial Lighting"

Industrial Lighting is one branch of lighting requiring immediate attention. This phase of lighting can contribute so much to our war effort that we can not afford to neglect it. Good lighting can increase production, reduce spoilage, reduce accidents, improved working conditions, reduce eyestrain, and help in other ways.

For this reason the bulletin "American Recom-

conditions, reduce eyestrain, and help in other ways.

For this reason the bulletin "American Recommended Practice of Industrial Lighting" approved by the American Standards Association, March 17, 1942, and just published by the Illuminating Engineering Society, is particularly timely. We are pleased to present you with a copy, which is enclosed.

You will note, on pages 5 to 8, the eminent organizations which have collaborated in the preparation of this bulletin. Already this "Recommended Practice of Industrial Lighting" is serving as an authoritative basis for the design of lighting in various war industries.

Yours very truly,

J. W. Bateman.

Manager, Lighting Service Department.

JWBateman:MC
Encl.

Organization Represented	*Name and Business Affiliation*	*Classification (See Summary)*
The American Society of Mechanical Engineers.	Alexander W. Luce, (Prof.) Mechanical Engineering Dept., University of Connecticut, Storrs, Connecticut.	E
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Association of Iron and Steel Engineers.	Edward C. Marshall, Chief Electrical Engineer, Youngstown Sheet and Tube Company, Youngstown, Ohio.	B
Edison Electric Institute.	W. T. Blackwell, Public Service Electric and Gas Company, 80 Park Place, Newark, New Jersey.	G
(Alternate)	H. E. Kent, Engineer, Edison Electric Institute, 420 Lexington Avenue, New York, N. Y.	
Federal Security Agency—Public Health Service.	P. A. Neal (Dr.), Chief, Research Section, National Institute of Health, Bethesda, Maryland.	D
Illuminating Engineering Society.	H. B. Dates, (Prof.) 3071 Euclid Heights Blvd., Cleveland, Ohio.	E
	Willard C. Brown, General Electric Company, Nela Park, Cleveland, Ohio.	A
International Association of Governmental Labor Officials.	Clyde McClure, Chemical Engineer, Division of Factory Inspection, Illinois Department of Labor, 205 West Wacker Drive, Chicago, Illinois.	D
International Association of Industrial Accident Boards and Commissions.	Joseph A. Haller, Director of Safety, State Industrial Accident Commission, Equitable Bldg., Baltimore, Maryland.	D

Organization Represented	*Name and Business Affiliation*	*Classification (See Summary)*
The National Association of Cotton Manufacturers.	F. M. Gunby, (Colonel) Charles T. Main, Inc., 201 Devonshire Street, Boston, Massachusetts.	B
National Association of Mutual Casualty Companies.	F. W. Braun, Vice-Pres. and Chief Engineer, Employers Mutual Liability Insurance Co. of Wisconsin, Wausau, Wisc.	F
National Bureau of Standards, U. S. Dept. of Commerce.	R. P. Teele, Photometry and Colorimetry Section, National Bureau of Standards, Washington, D. C.	D
The National Conservation Bureau.	William A. Weir, Superintendent, Safety Engineering Section, Commercial Casualty & Insurance Company, 10 Park Place, Newark, New Jersey.	F
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National Electrical Manufacturers' Association.	E. C. Huerkamp, Westinghouse Electric & Mfg. Co., 1216 West 58th Street, Cleveland, Ohio.	A
	S. R. Naysmith, Merchandise Manager, The Miller Company, 99 Center Street, Meriden, Connecticut.	A
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National Safety Council.	J. S. Shaw, Safety Director, Hercules Powder Company, Wilmington, Delaware.	B

Organization Represented	*Name and Business Affiliation*	*Classification (See Summary)*
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National Society for the Prevention of Blindness.	Charles P. Tolman, Consulting Engineer, National Society for the Prevention of Blindness, 1790 Broadway, New York, N. Y.	E
U. S. Department of Labor.	E. W. Edwards, Legislative Representative, New York State Federation of Labor, 9 South Hawk Street, Albany, New York.	C
	J. S. Rogers, Industrial Hygienist, Division of Labor Standards, Department of Labor, Washington, D. C.	D
U. S. Navy Department Bureau of Yards & Docks	W. G. Hill, Senior Electrical Engineer, Bureau of Yards and Docks, Navy Department, Washington, D. C.	B
U. S. War Department	John R. Gramm, Senior Engr. Office of the Quartermaster General, Room 2343, Munitions Building, Washington, D. C.	B

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American Recommended Practice of Industrial Lighting

INTRODUCTION

IN 1915 the Illuminating Engineering Society prepared and issued a Code of Lighting: Factories, Mills and Other Work Places. A revision of the Code under the procedure of the American Standards Association was made in 1921 and again in 1930.

The American Recommended Practice of Industrial Lighting herein presented constitutes a revision of the Code of Lighting: Factories, Mills and Other Work Places prepared under the sponsorship of the Illuminating Engineering Society and adopted on August 18, 1930, as an American Standard under the procedure of the American Standards Association.

In this new edition the primary purpose has been to present the principles of good lighting practice, the vital correlation between lighting and plant safety, the salient differences between good and poor illumination and some of the precautions which must be observed before adequate and suitable lighting (and hence good seeing) can be achieved and maintained.

This Recommended Practice of Industrial Lighting has been approved by the Sectional Committee, organized under the procedure of the American Standards Association, and by the Illuminating Engineering Society.

Inquiries and suggestions relative to the subject matter should be addressed to the American Standards Association, 29 West 39th Street, New York, New York.

ADVANTAGES OF GOOD ILLUMINATION

Illumination is a factor of primary importance which affects environment in every industrial establishment. The beneficial effects of good illumination, both natural and artificial, have been established in extensive tests over many years. The advantages to industry are many:

1. Greater accuracy of workmanship, resulting in an improved quality of product with less spoilage and rework.
2. Increased production and decreased costs.
3. Better utilization of floor space.
4. Greater ease of seeing, especially among older employees, thus making them more efficient.

FIG. 1—Continuous rows of industrial fluorescent units on 10-foot, 8-inch centers provide 40 footcandles of well-diffused light in this large factory area.

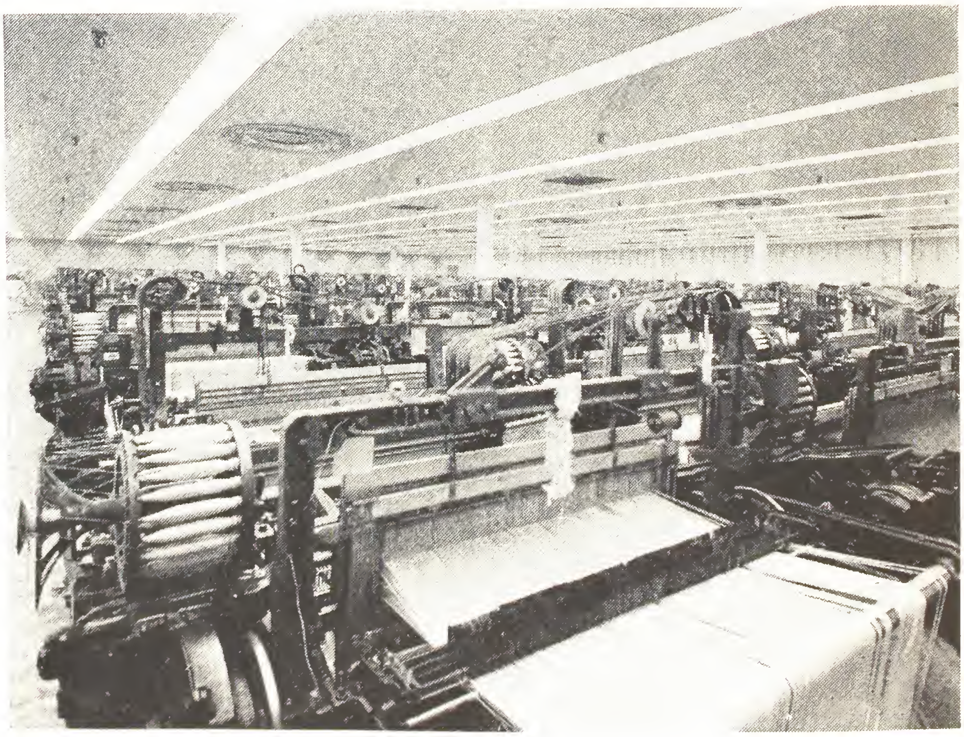

FIG. 2—Single rows of white 48-inch fluorescent lamps in troughs recessed in acoustic ceiling gave an initial illumination of 60 footcandles in this weave room. Ceiling height 9 feet. Distance between rows, 5 feet, 4 inches. Room area, approximately 11,000 square feet.

FIG. 3—Assembly and inspection of fine instruments. General lighting, 500-watt industrial diffusers supplemented by fluorescent lighting, provides maximum seeing conditions for the workmen.

5. More easily maintained cleanliness and neatness in the plant.
6. Less eyestrain among employees.
7. Better supervision of workers.
8. Improved morale among employees, resulting in decreased labor turnover.
9. Greater safety.

Illumination and Accuracy of Workmanship[1]

Under good illumination it is possible to see an object of much smaller size than is discernible under poor illumination.[2] Thus a much closer check can be made throughout the manufacturing process which will result in a much earlier discovery of visible defects, permitting rejection prior to final inspection. (Fig. 3)

Increased Production

It takes time to see—the eye is somewhat like a camera in this respect. An increase in illumination from one footcandle to a moderate level of approximately 20 footcandles (a condition often occurring upon the installa-

[1] The Effect of Brightness on the Precision of Visually Controlled Operations, P. W. Cobb and Frank K. Moss, *Journal Franklin Institute*, 199, 1925, 507.

[2] The Four Variables of the Visual Threshold, P. W. Cobb and Frank K. Moss, *Journal Franklin Institute*, 205, 1928, 831.

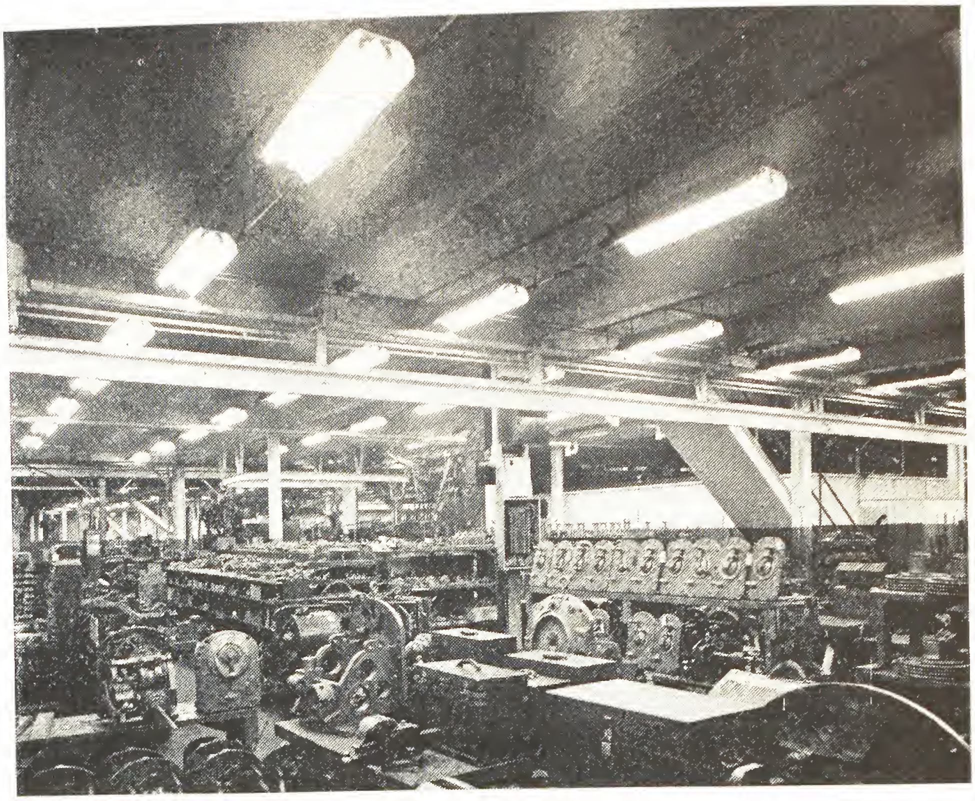

FIG. 4—A well lighted metal working factory area where attention to fine detail is important. Fluorescent industrial fixtures spaced on 8 by 9-foot centers, ceiling height 12 feet. Two 48-inch lamps per fixture. Illumination on work benches, 40 footcandles.

tion of a modern lighting system) results in increasing the speed of seeing approximately three times.[3] This enormous improvement in perception and recognition of surroundings affects practically everything the workman does. It reduces the time required for seeing (Fig. 4) and some of this time, at least, becomes available for production. The experiences of many plants which have improved their lighting bear out this point.[4]

Better Utilization of Floor Space[5]

A uniform level of general lighting makes possible the most efficient arrangement of machinery and conveyors and better utilization of floor space. Manufacturers have discovered that more work can be achieved with less floor space when the work flows in straight lines through assembly or inspection sections. Good lighting facilitates such proper arrangement of the work and practically eliminates the likelihood for crowding. (Fig. 5)

Improvement in Seeing Ability of Older Employees

Very frequently the older employee is well fitted physically and mentally for the responsible work for which his years of experience have prepared him.

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[3] The Science of Seeing, M. Luckiesh and F. K. Moss, D. Van Nostrand Co., p. 157.

[4] The Relation of Illumination to Production, D. P. Hess and Ward Harrison, *Transactions I. E. S.*, 18, 1923, 787-800.

[5] Operating Advantages of Controlled Conditions Plants, W. J. Austin, ILLUMINATING ENGINEERING, Vol. 36, 1941, 99-115.

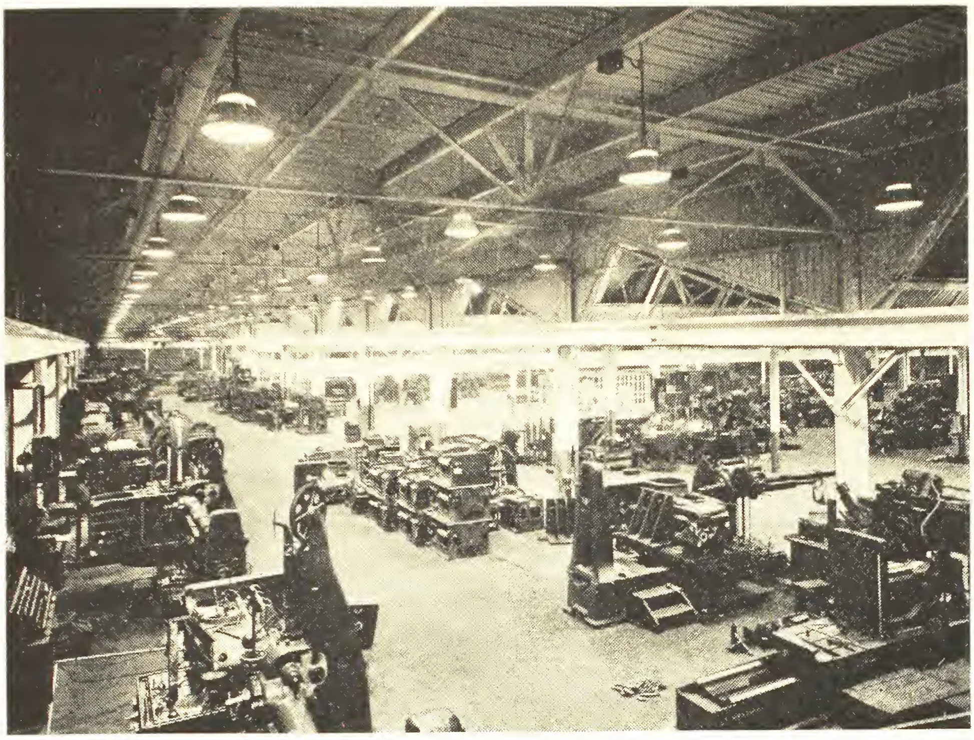

Fig. 5—Well-distributed lighting in machine shop permits maximum utilization of floor area, 750-watt filament lamps alternating with H-1 mercury lamps in prismatic reflectors. Mounting height, 22 feet; spacing, 14 feet, 4 inches by 13 feet, 8 inches. Illumination, 45 foot-candles.

In many cases, however, failing vision will prevent such an employee from carrying on exacting work and thus he is relegated to simple routine tasks in which his experience is of little value. It is desirable to preserve the experience of the older worker and receive the advantage of his long accumulated skill and knowledge.

It has long been known that as the eyes grow older there is a progressive loss in visual acuity and the prevalence of defective vision increases markedly. Much can be done to give assistance to eyes that are defective. Eyeglasses may correct refractive errors and permit the eyes to focus upon near and far objects. Higher illuminations are likewise an effective aid toward better seeing.

Many of these valuable, skilled, older workmen can continue to perform efficiently if the simple expedient of assisting their eyes with good illumination is adopted.

Less Eyestrain among All Employees

It should not be construed that good lighting is of assistance only to the older employees. Thirty-nine per cent of all workers of thirty years of age are visually handicapped.[6] It also aids *all* the visually handicapped to a

[6] Seeing and Human Welfare, M Luckiesh, Williams & Wilkins Co., Page 118.

FIG. 6—Accidents do not have much chance to occur in this well-lighted shop. The well-diffused uniform illumination floods every part of the room, rendering possible accident causes highly visible. Mercury and incandescent lamp units spaced on $16\frac{1}{2}$-foot centers, mounting height 40 feet. Average illumination, 26 footcandles. Note the cheerful effect produced by the white walls and ceiling.

greater extent than those with perfect vision, but even those in the latter group find, under good lighting, a noticeable improvement in eye comfort which results in reduced fatigue.

Improved Morale of the Employees

There is an important psychological effect connected with cheerful, pleasant, modern working surroundings as compared to the dim, gloomy interiors which were formerly so prevalent. (Fig. 6) In addition to the more cheerful appearance of a well-lighted interior, many minor frustrations due to poor lighting which continually harass the workmen, such as difficulty in reading scales and micrometers, finding the proper drills or other tools, are eliminated.

Plant Cleanliness

All industry has found that cleanliness invariably pays. Poor illumination makes it difficult to see into corners or under machinery and these dark areas inevitably collect dirt and waste which would otherwise be cleaned out. Where dirt can be seen it is more likely to be removed. In the well-lighted

Fig. 7—Good lighting promotes plant cleanliness. 54-inch R.F. fluorescent lamps in industrial reflectors provide 25 footcandles for heavy machine work. Mounting height, 11 feet, 6 inches. Spacing, 10 x 10 feet.

plant such dingy areas do not exist and much more sanitary conditions prevail. (Figs. 7 and 8)

In industrial plants that have their own engineering departments, it is desirable that the combined efforts of the electrical engineering department, the operating department and the safety department be enlisted to secure adequate maintenance of lighting equipment and to study lighting problems.

It is urged that those plants which do not have engineering departments should consult a competent illuminating engineer.

LIGHT AND SAFETY

Engineering for safe plant operation consists essentially of preparing a safe environment for the workman. The environment should be designed to match and to compensate for the limitations of human capability. On the other hand, the workman must understand his personal responsibilities regarding acts which might conceivably cause injury to himself or to others, and carefully follow plant safety regulations. The admirable activities of those organizations and individuals interested in the promotion of safety are successfully implanting this sense of responsibility in the individual workman.

FIG. 8—Food industries find cleanliness an essential element. Pineapple canning. Fluorescent lamps in industrial reflectors arranged in rows 10 feet apart over trimming tables and 20 feet apart over packing tables, provide 35 footcandles on trimming tables and 20 footcandles on the packing tables.

However, as revealed by an analysis of accidents and their causes, this is but one phase of the safety problem. All personal injury accidents involve a combination of personal and mechanical causes. The chain of circumstances or series of causes which has brought a workman to the verge of an injury frequently can be broken only if the workman can see quickly and accurately the causes and hence act to prevent the accident.

Any factor which aids seeing will increase the probability that the man will detect the causes of an accident and act to avert it. It is realized that with rapidly-moving material, mechanical failures often result in accidents occuring too rapidly for any reaction on the part of the workman. However, mechanical failures of this nature are usually preceded by evidences of the existence of undue stresses or strains which may be detected if sufficient illumination is provided.

Fewer Accidents

The close correlation between the personal injury rates and illumination is not generally understood. (Fig. 9) In most cases where accidents are attributed to poor illumination they occur because there is improper quality

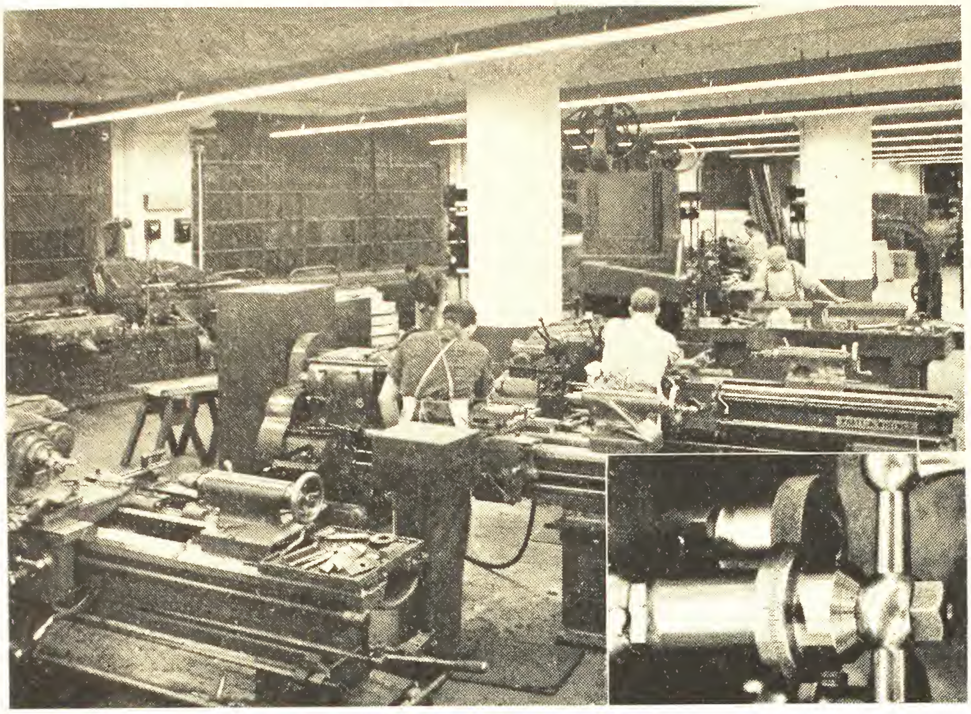

FIG. 9—Precision tool room. Industrial luminaires installed in continuous rows spaced 10 feet apart. Two 48-inch fluorescent lamps per luminaire. Mounting height 10 feet. Illumination 40 footcandles.

INSERT: Note the unusually high visibility of the working dial as seen under this type of illumination.

of illumination or practically no illumination at all. Poor or indifferent lighting as a contributing cause of accidents (even though it may provide measurable quantities of light) has been overlooked by most people. Many factors associated with poor illumination, such as glare, light reflected from the work, and dark shadows, hamper seeing and cause after-images and excessive visual fatigue which are important contributing causes of industrial accidents. Many accidents are also caused by delayed eye adaptation when coming from bright surroundings into dark interiors. Frequently accidents which are attributed to the individual's carelessness can actually be traced to difficulty of *seeing*.[7]

One important cause of industrial losses is the minor accident where the employee may or may not report for first aid but continues his work, but with a decrease in the quantity and quality of his work.

The condition of the illumination at the point of accident and in the surrounding area, should always be inspected and reported in accident investigations.

[7] Light and Sight—First Aid for Safety and Production, R. E. Simpson, *Transactions I. E. S.*, 23, 1928, 633.

FACTORS OF GOOD ILLUMINATION

There are many factors involved in good illumination. Because of this, lighting installations should be designed by a competent illuminating engineer. However, those who live with the lighting and those who must justify its cost should be acquainted with some of the factors to be considered. These can be summed up under the headings of *quality*, which includes the color of light, its direction, diffusion, absence of glare, etc., and *quantity*, or the amount of illumination.

QUALITY OF LIGHTING

The quality of the lighting[8] whether natural or artificial is highly important in providing good seeing conditions. Glare, diffusion, direction, and distribution have significant effects on visibility and the ability to see easily, accurately and quickly.

Glare

Glare[9, 10, 11] may be defined as any brightness within the field of vision of such character as to cause discomfort, annoyance, interference with vision, or eye fatigue. It is one of the most common and serious faults of lighting installations.

Glare is objectionable because: (1) when continued it tends to injure the eye and disturb the nervous system; (2) it causes discomfort and fatigue and thus reduces the efficiency of the workman and (3) it interferes with, and often prevents, clear vision and thus reduces efficiency, and in many cases increases the risk of accidents or injury to the workmen. From both a humanitarian and a business viewpoint, the owner or operator of a factory should be interested in avoiding glare whether caused by daylight or by artificial light.

There are two common forms of glare, "direct" and "reflected." Direct glare is caused by excessive brightness or brightness-contrast within the visual field, that is unshielded lamps or high-brightness surfaces of fixtures.

To reduce direct glare from the artificial lighting, direct general-lighting luminaires should be mounted at a sufficient height to keep them well above the normal line of vision. They should be properly designed to limit both the brightness and the quantity of light emitted in directions directly below the horizontal since such light is well within the normal field of view and interferes with vision.

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8 Quality of Lighting, M. Luckiesh and Frank K. Moss, *Transactions I. E. S.*, 30, 1935, 351.

9 The Fundamentals of Glare and Visibility, L. L. Holladay, *J. O. S. A.*, 12, 1926, 271.

10 Glare—Its Manifestations and the Status of Knowledge Thereof, P. S. Millar and S. McK. Gray, *Proceedings of the International Commission on Illumination*, 1928, 239.

11 What is Wrong with Our 50-Footcandle Installations? Ward Harrison, *Transactions I. E. S.*, 32, 1937, 208.

High brightness-contrasts should be avoided. For example, an unshielded lamp viewed against the low brightness of a dark ceiling may be very glaring, similarly, a bright window seen against darker surrounding walls. Fig. 10 indicates the extent to which visibility is decreased as a glare source approaches the line of vision.

Supplementary lighting sources should be carefully designed so that the light is confined to the immediate working area. Failure to observe this precaution may cause extreme annoyance not only to the workman using the source but to others in the vicinity. Care should also be exercised to prevent excessive brightness-contrasts between the work and the surroundings.

Reflected glare, as its name implies, is caused by high brightnesses, images or brightness-contrasts reflected from ceilings, walls, desk tops, or other surfaces within the visual field such as materials and machines. These brightnesses are accentuated when the surfaces are glossy or specular in character, such as highly-polished machine parts, smooth-finished surfaces, varnished table tops or other highly-reflective surfaces. Reflected glare is frequently more annoying than direct glare because it is so close to the line of vision that the eye cannot avoid it. The effect of reflected glare for a given image brightness is reduced with higher levels of general illumination due to the reduction in contrast.

Diffusion and Distribution[8] of Light

Some directional and shadow effects are desirable in general illumination for accentuating the depth and form of solid objects, but harsh shadows should be avoided. Shadows are softer and less pronounced when diffusing units and units having a wide distribution of light are used, since then the object is illuminated from many sources. Alternate light and dark areas in strong contrast are undesirable because the eye has difficulty in adjusting itself for the two illuminations and seeing becomes tiring. For this reason, purely local lighting restricted to a small work area is unsatisfactory unless there is sufficient general illumination in the room.

Clearly defined shadows, without excessive contrast, are a distinct aid to sight in certain types of operations such as engraving on polished surfaces, scribed layout work, and textile inspection. When such shadow effect is indicated, it is best obtained by supplementary directional light combined with diffused illumination of ample intensity.

Much attention has been given to measurement of footcandles on the horizontal plane. Actually many of the seeing tasks in industry are on vertical or nearly vertical surfaces. Hence the amount and the distribution of light on vertical surfaces may be of great importance. (Fig. 11)

FIG. 10—(Left) It is actually possible to measure the loss in seeing caused by glare. Here more than half of the useful light has been wasted.

FIG. 11—(Right) The amount and the distribution of light on vertical as well as on horizontal surfaces is often of great importance. Installation of fluorescent lamps in continuous rows of industrial reflectors provides 80 footcandles on the horizontal and 45 footcandles on the vertical for the difficult seeing tasks in this meter department.

Color Quality of Light

It appears that with equal footcandles of illumination, variations in color quality of light have little or no effect upon clearness and quickness of seeing.[12, 13] However, in certain industries color discrimination is highly important, and light sources which provide lighting that will enable the matching to be carried on most accurately should be used. This again is a matter in which the illuminating engineer should be consulted.

Color of Surroundings

Light-colored surfaces serve several purposes in the factory. They are of particular value in providing a high utilization of light because they reflect more light toward the working areas. Also, bright window areas and artificial light sources are less uncomfortable to the eye when viewed against light backgrounds.

Many progressive concerns are painting all of their machinery with light-tinted durable paints. This provides an increased amount of light which is reflected to the otherwise shadowed sections of the machine. Some manufacturers paint stationary and moving parts of machines different colors to prevent accidents by thus aiding perception.

QUANTITY OF LIGHT

The desirable quantity of light for any particular installation depends primarily upon the work which is being done. The degree of accuracy, the fineness of detail to be observed, the color and reflectivity of the work as well as of the immediate surroundings materially affect the distribution of brightness which will produce maximum seeing conditions. Investigations in the field and laboratory have proved that as the illumination on the task is increased, the ease, speed and accuracy with which the task can be accomplished are increased. These tests have not yet established an upper limit but the harmful effects of low-footcandle values are well known.[14]

With the aid of the Luckiesh-Moss Visibility Meter,[15] it is now possible to determine the relative ease of seeing two objects. (Fig. 12) It is a most valuable instrument in the hands of one trained in its use and familiar with the operation being checked.

It is possible to measure quantity of light quickly and reasonably accurately with any of the various meters employing light-sensitive cells. (Fig. 13)

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[12] Seeing in Tungsten, Mercury and Sodium Lights, M. Luckiesh and Frank K. Moss, *Transactions I. E. S.*, 31, 1936, 655.

[13] Comparison of the Light from High Intensity Mercury Vapor Lamps and Incandescent Filament Lamps for Visual Tasks, C. S. Woodside and Harris Reinhardt, *Transactions I. E. S.*, 32, 1937, 365.

[14] The Science of Seeing, M. Luckiesh and Frank K. Moss, D. Van Nostrand Company, New York, N. Y., 1937.

[15] Visibility—Its Measurement and Significance in Seeing, M. Luckiesh and Frank K. Moss, *Journal of Franklin Institute*, 220, 1935, 431.

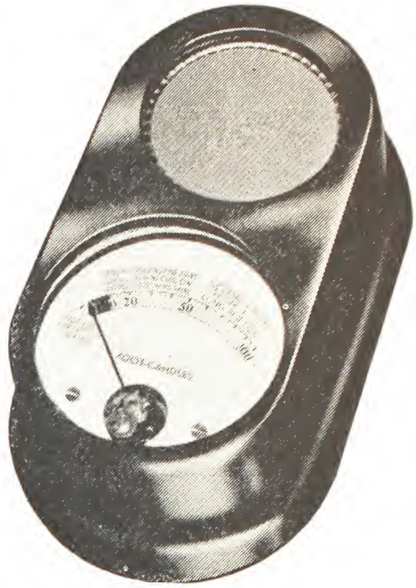

Fig. 12—The visibility meter makes it possible for the skilled engineer to compare the ease of seeing two different tasks.

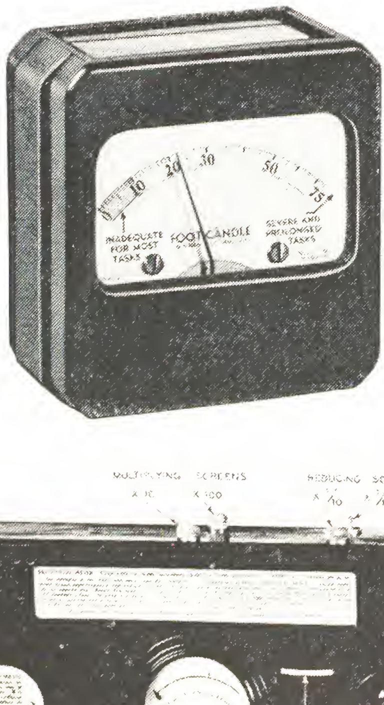

Fig. 13—Light meters are self-contained and direct-reading. With them anyone can quickly measure the amount of light at a given place.

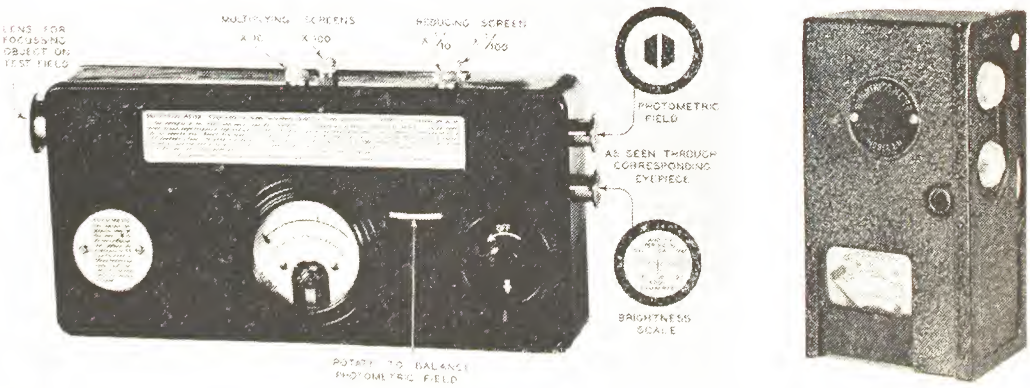

Fig. 14—The Brightness meter. Luckiesh-Taylor at left. Luckiesh-Holladay at right. In some cases brightness rather than quantity of light is the criterion for satisfactory seeing conditions.

These instruments* are direct-reading and simple, but they should be calibrated at frequent intervals. It is highly important that the measurement be made at the point and in the plane in which the seeing task is performed, whether it be horizontal, vertical, or at some intermediate angle. If lighting is a combination of natural and artificial illumination, that part due to natural light should be measured separately from that due to the artificial light, since in many cases, at one hour of the day there is a great amount of natural light while at a different time it may fail entirely.

Brightness measurements hitherto difficult of accomplishment are now easily made with a Brightness Meter (Fig. 14), such as the Luckiesh-Taylor; Luckiesh-Holladay and Macbeth.

Recommended Minimum Standards of Illumination

The majority of the recommended values of illumination in the following table refer to the general lighting or lighting throughout the total area involved as measured on a horizontal plane 30 inches above the floor. In some cases where an illumination of more than 50 footcandles is necessary, it may be obtained by a combination of general lighting plus supplementary lighting at the point of work. An asterisk after the footcandle figure denotes that the combination of general and supplementary illumination is desirable.

The Illuminating Engineering Society has been studying the illumination needs of specific industries in recent years.[16, 17, 18, 19, 20, 21, 22, 23] Wherever reports of these industries have been completed, the footcandles included in Table I are taken from that report. In other cases, the values are based upon current good practice. These reports should be consulted for detailed lighting specifications for manufacturing processes.

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* More accurate, larger meters are available, equipped with corrective filters which permit direct reading of any common type of illuminant. The filters correct for the differences in color of the various sources, giving a response which is similar to that of the human eye. These larger meters should be used for the more accurate investigations.

[16] Progress Report on Lighting in the Printing Industry, Committee on Industrial and School Lighting, *Transactions I. E. S.*, 31, 1936, 277–313.

[17] Report on Lighting in the Textile Industry—Grey Goods and Denim, Committee on Industrial and School Lighting, *Transactions, I. E. S.*, 32, 1937, 247–281.

[18] Report on Lighting in the Shoe Manufacturing Industry, Committee on Industrial and School Lighting, *Transactions I. E. S.*, 32, 1937, 289–314.

[19] Report on Lighting in the Candy Manufacturing Industry, Committee on Industrial and School Lighting, *Transactions I. E. S.*, 32, 1937, 483–504.

[20] Studies in Lighting of Intricate Production, Assembly and Inspection Processes, Committee on Industrial and School Lighting, *Transactions I. E. S.*, 32, 1937, 1019–1053.

[21] Lighting for Silk and Rayon Throwing and Wide Goods Weaving, Committee on Industrial and School Lighting, *Transactions I. E. S.*, 33, 1938, 17–52.

[22] Lighting for the Machining of Small Metal Parts, Committee on Industrial and School Lighting, *Transactions I. E. S.*, 34 1939, 21–54.

[23] Lighting of Power Presses, Committee on Industrial and School Lighting, *Transactions I. E. S.*, 34, 1939, 153–175.

Attention is called to the fact that the values given are minimum operating values; that is, they apply to measurements of the lighting system in use, not simply when the lamps and reflectors are new and clean—and in almost every instance higher values may be used with greater benefit.

FOOTCANDLE—The amount of illumination at a point on a plane one foot distant from a source of one candlepower and perpendicular to the light rays at this point.

TYPICAL DAYLIGHT READINGS:

Direct sunlight at noon	8,000 to 10,000 footcandles
Shade of a tree or under heavy overcast sky	500 to 1,000 footcandles
Indoors, at window, bright day	100 footcandles
Indoors, average room, 20 feet from window	5 footcandles

To insure that a given illumination will be maintained even where conditions are favorable it is necessary to design the system to give initially at least 25 per cent more light than the required minimum. In locations where the dirt will collect rapidly and where adequate maintenance is not provided, the initial value should be at least 50 per cent above the minimum requirement.

Where safety goggles are worn the light reaching the eye is likely to be materially reduced and the general level of lighting should, therefore, be increased accordingly in such locations.

TABLE I—MINIMUM FOOTCANDLES IN SERVICE

Recommended Minimum Standards of Illumination for Industrial Interiors

(These footcandle values represent order of magnitude rather than exact levels of illumination)

	Minimum Footcandles in Service Measured 30 inches Above the Floor
Assembly:	
Rough	10
Medium	20
Fine	B*
Extra Fine	A*
Automobile Manufacturing:	
Assembly Line	B*
Frame Assembly	20
Body Manufacturing—	
Parts	20
Assembly	20
Finishing and Inspecting	A*
Bakeries	20
Book Binding:	
Folding, Assembling, Pasting, etc.	10
Cutting, Punching and Stitching	20
Embossing	20
Breweries:	
Brew House	5
Boiling, Keg Washing and Filling	10
Bottling	20
Candy Making:	
Box Department	20
Chocolate Department—	

* See reference footnote at end of Table.

TABLE I—*Continued*

	Minimum Footcandles in Service
Husking, Winnowing, Fat Extraction, Crushing and Refining, Feeding	10
Bean Cleaning and Sorting, Dipping, Packing, Wrapping	20
Milling	30
Cream Making—	
Mixing, Cooking and Molding	20
Gum Drops and Jellied Forms	20
Hand Decorating	50
Hard Candy—	
Mixing, Cooking and Molding	20
Die Cutting and Sorting	30
Kiss Making and Wrapping	30
Canning and Preserving	20
Chemical Works:	
Hand Furnaces, Boiling Tanks, Stationary Driers, Stationary and Gravity Crystallizers	5
Mechanical Furnaces, Generators and Stills, Mechanical Driers, Evaporators, Filtration, Mechanical Crystallizers, Bleaching	10
Tanks for Cooking, Extractors, Percolators, Nitrators, Electrolytic Cells	15
Clay Products and Cements:	
Grinding, Filter Presses, Kiln Rooms	5
Molding, Pressing, Cleaning and Trimming	10
Enameling	15
Color and Glazing	20
Cleaning and Pressing Industry:	
Checking and Sorting	20
Dry and Wet Cleaning and Steaming	10
Inspection and Spotting	A*
Pressing—	
Machine	20
Hand	50
Receiving and Shipping	10
Repair and Alteration	50
Cloth Products:	
Cutting, Inspecting, Sewing—	
Light Goods	20
Dark Goods	A*
Pressing, Cloth Treating (Oil Cloth, etc.)—	
Light Goods	10
Dark Goods	20
Coal Tipples and Cleaning Plants:	
Breaking, Screening and Cleaning	10
Picking	A*
Construction—Indoor:	
General	10
Elevators—Freight and Passenger	10
Engraving.	A*
Forge Shops and Welding	10
Garages—Automobile:	
Storage—Live	10
Storage—Dead	2
Repair Department and Washing	30
Glass Works:	
Mix and Furnace Rooms, Pressing and Lehr, Glass Blowing Machines	10
Grinding, Cutting Glass to Size, Silvering	20
Fine Grinding, Polishing, Beveling, Etching and Decorating	50 C*
Inspection	B* C*
Glove Manufacturing:	
Pressing, Knitting, Sorting—	
Light Goods	10
Dark Goods	20
Cutting, Stitching, Trimming, Inspection—	
Light Goods	20
Dark Goods	A*

* See reference footnote at end of Table.

TABLE I—*Continued*

	Minimum Footcandles in Service
Hangars—Aeroplane:	
Storage—Live	10
Repair Department	50
Hat Manufacturing:	
Dyeing, Stiffening, Braiding, Cleaning and Refining—	
Light	20
Dark	30
Forming, Sizing, Pouncing, Flanging, Finishing and Ironing—	
Light	20
Dark	30
Sewing—	
Light	20
Dark	A*
Ice Making—Engine and Compressor Room	10
Inspection:	
Rough	20
Medium	30
Fine	B*
Extra Fine	A*
Iron and Steel Manufacturing:**	
Jewelry and Watch Manufacturing	A*
Laundries	20
Leather Manufacturing:	
Vats	5
Cleaning, Tanning and Stretching	10
Cutting, Fleshing and Stuffing	20
Finishing and Scarfing	30
Leather Working:	
Pressing, Winding and Glazing—	
Light	10
Dark	20
Grading, Matching, Cutting, Scarfing, Sewing—	
Light	20
Dark	A*
Locker Rooms	10
Machine Shops:	
Rough Bench and Machine Work	20
Medium Bench and Machine Work, Ordinary Automatic Machines, Rough Grinding, Medium Buffing and Polishing	30
Fine Bench and Machine Work, Fine Automatic Machines, Medium Grinding, Fine Buffing and Polishing	B*
Extra Fine Bench and Machine Work, Grinding—	
Fine Work	A*
Meat Packing:	
Slaughtering	10
Cleaning, Cutting, Cooking, Grinding, Canning, Packing	20
Milling—Grain Foods:	
Cleaning, Grinding and Rolling	10
Baking or Roasting	20
Flour Grading	30
Offices:	
Bookkeeping, Typing and Accounting	50
Business Machines — Power Driven (Transcribing and Tabulating)—	
Calculators, Key Punch, Bookkeeping	B*
Conference Room—	
General Meetings	25
Office Activities—See Desk Work	
Corridors and Stairways	5
Desk Work—	
Intermittent Reading and Writing	25
Prolonged Close Work, Computing, Studying, Designing, etc.	50

* See reference footnote at end of Table.

** Consideration is now being given to the proposition of issuing a report on Recommended Lighting Practice for the entire Iron and Steel Industry.

TABLE I—*Continued*

	Minimum Footcandles in Service
Reading Blueprints and Plans	30
Drafting—	
Prolonged Close Work—Art Drafting and Designing in Detail	50
Rough Drawing and Sketching	30
Filing and Index References	25
Lobby	10
Mail Sorting	25
Reception Rooms	10
Stenographic Work	50
Vault	10
Packing and Boxing	10
Paint Mixing	10
Paint Shops:	
Dipping, Simple Spraying, Firing	10
Rubbing, Ordinary Hand Painting & Finishing Art, Stencil and Special Spraying	20
Fine Hand Painting and Finishing	B*
Extra Fine Hand Painting and Finishing (Automobile Bodies, Piano Cases, etc.)	A*
Paper Box Manufacturing:	
Light	10
Dark	20
Storage	5
Paper Manufacturing:	
Beaters, Grinding, Calendering	10
Finishing, Cutting, Trimming, Paper Making Machines	20
Plating	10
Polishing and Burnishing	20
Power Plants, Engine Room, Boilers:	
Boilers, Coal and Ash Handling, Storage Battery Rooms	5
Auxiliary Equipment, Oil Switches and Transformers	10
Engines, Generators, Blowers, Compressors	20
Switchboards	30

	Minimum Footcandles in Service
Printing Industries:	
Type Foundries—	
Matrix Making, Dressing Type	A*
Font Assembly—Sorting	B*
Hand Casting	30
Machine Casting	20
Printing Plants:	
Presses	30
Imposing Stones A*	C*
Proof Reading	A*
Electrotyping:	
Molding, Finishing, Leveling Molds, Routing, Trimming	B*
Blocking, Tinning	30
Electroplating, Washing, Backing	20
Photo Engraving:	
Etching, Staging	20
Blocking	30
Routing, Finishing, Proofing	B*
Tint Laying	A*
Receiving and Shipping	10
Rubber Tire and Tube Manufacturing:	
Stock Preparation—	
Plasticating	20
Milling	20
Calendering	30
Branbury	20
Fabric Preparation—	
Stock Cutting	30
Bead Building	30
Tube Tubing Machines	20
Tread Tubing Machines	20
Tire Building—	
Solid Tire	20
Pneumatic Tire	50
Curing Department—	
Tube Curing	B*
Casing Curing	B*
Final Inspection—	
Tube	B*
Casing	A*
Wrapping	20
Warehouse	5

* See reference footnote at end of Table.

TABLE I—*Continued*

	Minimum Footcandles in Service
Mechanical Rubber Goods:	
Stock Preparation—	
Plasticating	20
Milling	20
Calendering	30
Branbury	20
Fabric Preparation—	
Stock Cutting	30
Hose Looms	30
Molded Products	B*
Extruded Products	30
Curing	B*
Inspection	A*
Boxing	20
Warehouse	5
Sheet Metal Works:	
Miscellaneous Machines, Ordinary Bench Work	20
Punches, Presses, Shears, Stamps, Spinning, Medium Bench Work . . . 20	C*
Tin Plate Inspection . . . B*	C*
Shoe Manufacturing (Leather)	
Cutting and Stitching—	
Cutting Tables	20
Marking, Buttonholing, Skiving, Sorting, Vamping and Counting—	
Light Materials	20
Dark Materials	50
Stitching—	
Light Materials	50
Dark Materials	B*
Making and Finishing—	
Stitchers, Nailers, Sole Layers, Welt Beaters and Scarfers, Trimmers, Welters, Lasters, Edge Setters, Sluggers, Randers, Wheelers, Treers, Cleaning, Spraying, Buffing, Polishing, Embossing—	
Light Materials	30
Dark Materials	50

* See reference footnote at end of Table.

	Minimum Footcandles in Service
Storage, Packing and Shipping	10
Shoe Manufacturing (Rubber):	
Washing, Coating, Mill Run Compounding	10
Varnishing, Vulcanizing, Calendering, Upper and Sole Cutting	30
Sole Rolling, Lining, Making and Finishing Processes	50
Soap Manufacturing:	
Kettle Houses, Cutting, Soap Chip and Powder	10
Stamping, Wrapping and Packing, Filling and Packing Soap Powder	20
Stairways, Passageways	5
Stone Crushing and Screening:	
Belt Conveyor Tubes, Main Line Shafting Spaces, Chute Rooms, Inside of Bins	5
Primary Breaker Room, Auxiliary Breakers under Bins	5
Screens	10
Storage Battery Manufacturing:	
Molding of Grids	10
Store and Stock Rooms:	
Rough Bulky Material	5
Medium or Fine Material Requiring Care	10
Structural Steel Fabrication	10
Sugar Grading	30
Testing:	
Rough	20
Fine	30
Extra Fine Instruments, Scales, etc.	A*
Textile Mills (Cotton):	
Opening, Mixing, Picking, Carding and Drawing	10
Slubbing, Roving, Spinning	20
Spooling, Warping on Comb	20
Beaming and Slashing on Comb—	

TABLE I—*Concluded*

	Minimum Footcandles in Service
Grey Goods	20
Denims	B*
Inspection—	
Grey Goods (Hand Turning)	50
Denims (Rapidly Moving)	A*
Automatic Tying-In, Weaving	B*
Drawing-In by Hand	A*
Weaving	25
Silk and Rayon Manufacturing:	
Soaking, Fugitive Tinting, and Conditioning or Setting of Twist	10
Winding, Twisting, Rewinding, and Coning, Quilling, Slashing	30
Warping (Silk or Cotton System) on Creel, on Running Ends, on Reel, on Beam, on Warp at Beaming	50
Drawing-In—	
On Heddles	A*
On Reed	A*
Weaving—	
On Heddles and Reeds	10
On Warp Back of Harness	20
On Woven Cloth	30
Woolen:	
Carding, Picking, Washing, Combing	15
Twisting, Dyeing	15
Drawing-In, Warping	A*
Weaving—	
Light Goods	25
Dark Goods	50
Knitting Machines	20
Tobacco Products:	
Drying, Stripping, General	10
Grading and Sorting	A*
Toilets and Wash Rooms	10
Upholstering—Automobile, Coach Furniture	20
Warehouse	5
Welding	30
Woodworking:	
Rough Sawing and Bench Work	15
Sizing, Planing, Rough Sanding, Medium Machine and Bench Work, Glueing, Veneering, Cooperage	20
Fine Bench and Machine Work, Fine Sanding and Finishing	50

* Lighting recommendations for the more difficult seeing tasks, as indicated by A, B, and C in the foregoing table, are given in he following:

Group A:

These seeing tasks involve (a) the discrimination of extremely fine detail under conditions of (b) extremely poor contrast, (c) for long periods of time. To meet these requirements, illumination levels above 100 footcandles are recommended.

To provide illumination of this order, a combination of at least 20 footcandles of general lighting plus specialized supplementary lighting is necessary. The design and installation of the combination systems must not only provide a sufficient amount of light but also must provide the proper direction of light, diffusion, eye protection, and insofar as possible must eliminate direct and reflected glare as well as objectionable shadows.

Group B:

This group of visual tasks involves (a) the discrimination of fine detail under conditions of (b) a fair degree of contrast (c) for long periods of time. Illumination levels from 50 to 100 footcandles are required.

To provide illumination of this order a combination of at least 20 footcandles of general lighting plus specialized supple-

mentary lighting is necessary. The design and installation of the combination systems must not only provide a sufficient amount of light but also must provide the proper direction of light diffusion, eye protection, and insofar as possible must eliminate direct and reflected glare as well as objectionable shadows.

Group C:

The seeing tasks of this group require the discrimination of fine detail by utilizing (a) the reflected image of a luminous area or (b) the transmitted light from a luminous area.

The essential requirements are (1) that the luminous area shall be large enough to cover the surface which is being inspected and (2) that the brightness be within the limits necessary to obtain comfortable contrast conditions. This involves the use of sources of large area and relatively low brightness in which the source brightness is the principal factor rather than the footcandles produced at a given point.

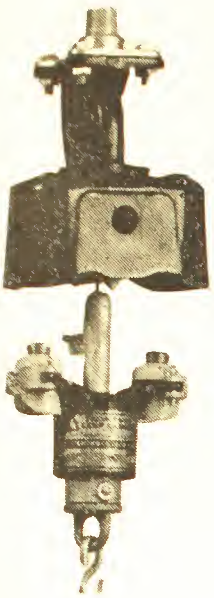
* * * *

MAINTENANCE OF ILLUMINATION

The proper and adequate maintenance of equipment is essential for both natural and artificial lighting. Systems which are adequate when first installed will soon deteriorate unless properly maintained. A regular, definite system of maintenance should be established so as to insure that skylights, side windows, lamps and accessories are at all times kept clean, in proper adjustment and in good repair. The recommended method of establishing a suitable maintenance schedule for the cleaning of lighting equipment is to check the illumination periodically with a light meter. When the illumination has decreased to 75 per cent of its initial value, the lighting equipment should be washed with a detergent (without free alkali) and warm water. Frequently a group-replacement plan of relamping can be established to coincide with the cleaning period with a resultant saving in maintenance costs.

Means should be provided for easy access to all lighting units. (Fig. 15) Walls and ceilings should be repainted, preferably in light tones, at regular intervals. With indirect lighting systems, it is essential that the ceiling be kept clean since the illumination comes from the ceiling. It should be remembered that the illumination requirements given in the tables apply to the lighting equipments *under average operating conditions*, not simply when new and clean as first installed.

Fig. 16 shows the very considerable loss in illumination which results from the collection of dirt on lamps and lighting units. To insure that a given illumination will be maintained even where conditions are favorable, it is necessary to design the system to give initially at least 25 per cent more light than the required minimum. In locations where the dirt will collect



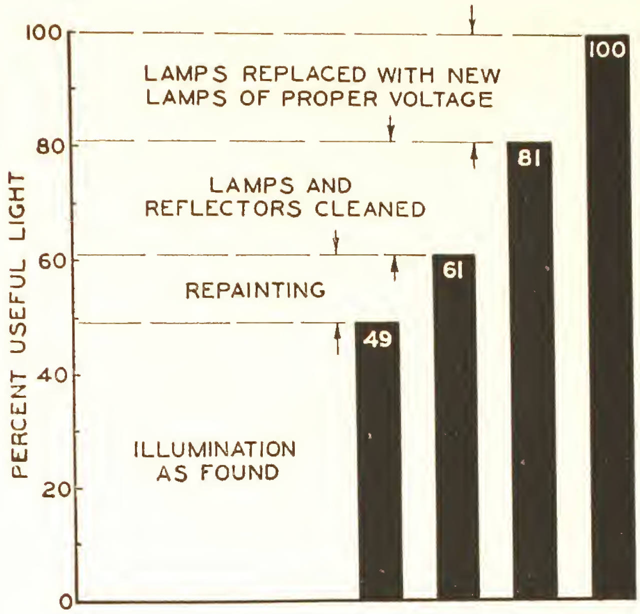


Fig. 15—(Left) Automatic disconnecting hangers enable the maintenance man to lower the fixture to the floor by means of a convenient chain.

Fig. 16—(Right) Striking improvements are obtained by repainting and cleaning lamps and reflectors. These data were obtained in a plant where conditions were unfavorable for maintenance.

rapidly and where adequate maintenance is not provided, the initial value should be at least 50 per cent above the minimum requirement. It is evident from a study of Fig. 16 that without adequate maintenance even this allowance may prove insufficient.

NATURAL LIGHTING

Factory owners in most industries are particularly interested in making the best possible use of their daylight facilities. The saw-tooth, monitor, or skylight windows of modern factory construction (Fig. 17) permit of an adequate and more uniform daylight illumination of the entire floor area, and are desirable when practicable.[24, 25] When rooms are illuminated through side windows, it is often difficult or impossible to light satisfactorily all parts of the floor space, furnishing adequate illumination to the workers without subjecting some of them to objectionable glare.

If only one wall contains windows, the width of the room perpendicular to this wall should be less than twice the height of the top of the windows above the floor; if windows are in two parallel walls, the width of the room between these walls should not exceed six times this window height. A monitor gives best results when its width is about half the width of the building, and the height of the windows in the monitor is one half of the

[24] Studies in Illumination, IV, Public Health Bulletin #218, Ives, Knowles and Thompson, Washington, 1935.

[25] A Bibliography of Natural Lighting, Higbie and Martin, *Transactions I. E. S.*, 24, 1929, 315.

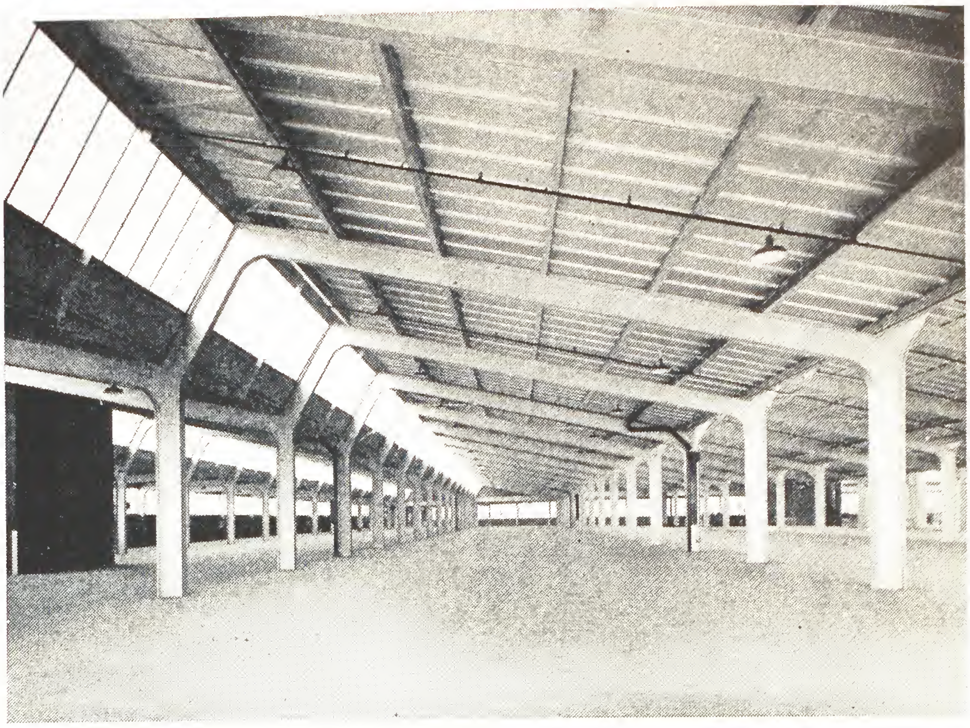


Fig. 17—Well-diffused daylight illumination is obtained with this modern rigid-frame saw-tooth construction.

monitor width. The height of the windows in saw-tooth construction should be at least one-third of the span. In general, single-story industrial buildings should have a window area of at least 30 per cent of the floor area. Where it is practicable to do so, provision should be made for hose connections on the roof to facilitate washing the windows.

Reflection of daylight from surfaces outside a building has an important effect upon the lighting of a room. Faces of structures, walls of courts, and roofs of saw-tooth buildings should be finished in the lightest practicable colors and so maintained. The possibility of glare from such surfaces should, however, be considered.

Windows should be equipped with adjustable devices so that the illumination may be accommodated to changing exterior conditions. Window shades of light tones should be used, for at night they will reflect artificial light back into the room; shades, transmitting diffusely a large part of the natural light they receive, will generally improve the daylight illumination. When practicable, shades should be mounted so as to permit the covering of any desired parts of the windows. Louvers or Venetian blinds employing reflecting and diffusing surfaces are an effective means to control the distribution of natural illumination as well as the glare from windows. Any devices for adjustment of natural lighting should be controlled by some specified individual.

Rapid changes in illumination levels results in a temporary inability to see, due to the time required for adaptation of the eyes. An example of this occurs when one steps from bright sunlight into a dimly-lighted interior. A passageway adjacent to a highly illuminated area, therefore, needs relatively high and graduated illumination. Again, where the eye has been afforded the advantages of a high illumination throughout the day and artificial light is turned on to reinforce the failing natural light, a higher total illumination is ordinarily needed than at night under artificial lighting alone.

Automatic Photoelectric Control of the Lighting System

Natural light is subject to variation throughout the day and no individual can be relied upon in practice to determine by visual observation when more light should be added in the room or when artificial lighting can be spared. Practical equipments utilizing photoelectric tubes or light-sensitive cells have been developed for controlling the lighting automatically, although not applicable to all installations. These photoelectric relays can be relied upon to follow the changes of daylight and make corrections when needed even though the variation is too gradual to attract attention. They will turn on the artificial lighting when the natural illumination at a given point in the room falls below a predetermined value. If the daylight illumination then increases sufficiently, they will turn off the light. The photoelectric relay does not lag behind or make mistakes. It assures good seeing conditions at all times with a minimum expenditure of electricity for lighting consistent with this result.

Automatic control is recommended particularly for locations where critical seeing is done with daylight illumination. Frequently a man engrossed in his work will not notice the gradual diminution of daylight until he realizes he has a headache or reaches the point where he simply cannot see. When this happens to an entire department, the loss in employee efficiency is serious. The photoelectric relay stands guard over such eventualities. It is an inexpensive means of avoiding the penalties of insufficient illumination when reliance is placed on daylight as the principal source of light.[26]

ARTIFICIAL LIGHTING

To maintain good seeing conditions artificial lighting must be supplied when daylight fails, as on dark and cloudy days or for the areas where an insufficient quantity of daylight penetrates. (Fig. 18) In some localities, deficient daylight conditions prevail during about two-thirds of the work-

[26] Cost of Lighting Industrial Buildings, L. L. Holladay, *Journal of Franklin Institute*, 207, 1929, 193.

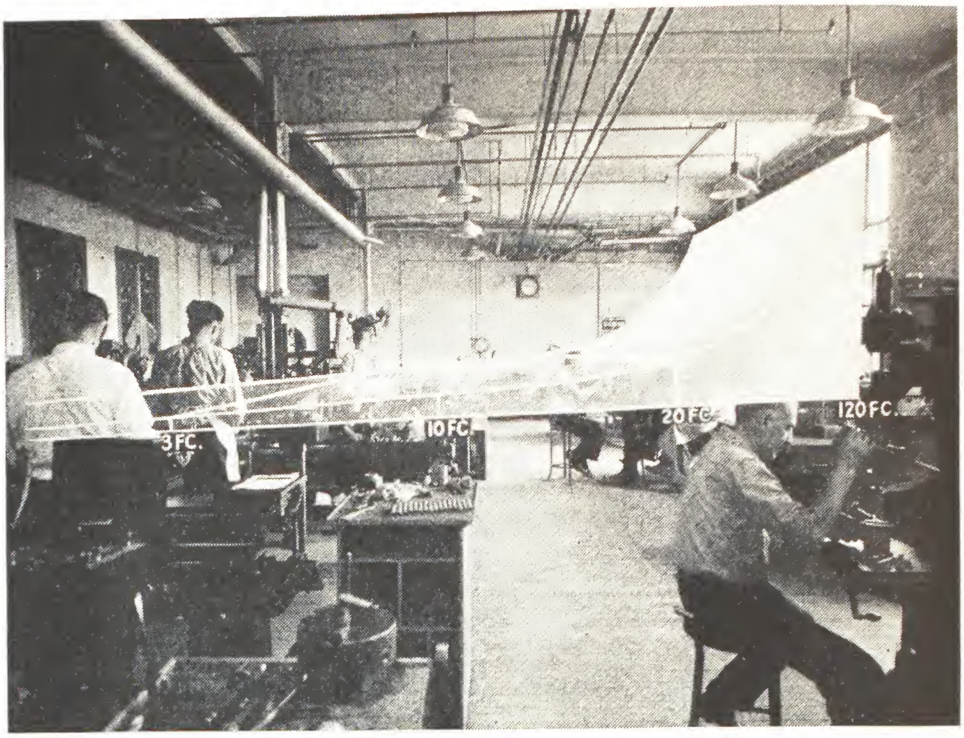


Fig. 18—Showing how rapidly daylight falls off with distance from the windows.

ing hours. Even in comparatively sunny territories, measurements show that desirable daylight conditions are lacking for a surprisingly large percentage of the time. For this reason, artificial lighting is essential to good plant operation.

With natural lighting, the space along the windows is, in most plants, the best lighted area, while with artificial lighting this space is too often the most poorly lighted. It is essential that the artificial lighting be so designed as to continue the general level of illumination close up to the windows and walls, thus insuring good lighting over the entire working area of the room, and to light the area adequately for night work.

GENERAL LIGHTING

Modern industrial lighting practice requires the establishment of a base or minimum quantity of light throughout the room, termed general lighting. This may vary depending upon the purpose for which the space is to be used. If the visual tasks are particularly severe, much higher illumination over restricted areas can be added upon this base. This additional light,[27] known as supplementary lighting, is usually provided by luminaires placed relatively close to the areas being illuminated. The general lighting system, in contrast, usually consists of luminaires placed 10 feet or more

[27] General Lighting Plus, M. Luckiesh and Frank K. Moss, *Transactions I. E. S.*, 24, 1929, 233.

FIG. 19—General lighting (direct). Alternate staggered mercury and filament system. Concentrating metal reflectors with 1000-watt, bi-post lamps, and two-lamp, metal mercury reflectors with two H-1 mercury lamps. Mounting height, 44 feet; spacing, 20 feet x 16 feet. Illumination 42 footcandles.

above the floor. The purpose of the general lighting system where there is also supplementary lighting is to keep the brightness contrast between the well-lighted immediate work area and the surroundings within a range which is comfortable to the eyes, to provide sufficient light for safety and protection, and to illuminate ordinary seeing tasks.

The general lighting, or the base quantity of light, should be quite uniform so that light will be available when needed at any point in the room. This is particularly desirable for interiors where the machine layout may be changed. If the general lighting has been designed for uniform illumination, machines may be moved without necessitating an expensive change in the overhead lighting system. (Figs. 19 and 20)

The manner in which the light from the lamp is controlled by the lighting equipment governs to a large extent the important effects of glare, shadows, distribution and diffusion. Luminaires* are classified in accordance with the way in which they control the light, as in Table II.

* Luminaire—A general term for a lighting unit comprising the light source and its direct appurtenances such as globe, reflector, refractor, housing and supports.

Fig. 20—General lighting (direct). A modern industrial area, 168 feet by 780 feet. Artificial lighting, continuous rows of industrial fluorescent reflectors (two 48-inch fluorescent lamps per reflector) spaced 10 feet apart; mounting height, approximately 12 feet. Illumination in service, 50 footcandles.

Fig. 21—Good seeing conditions in this machine tool plant. 750-watt incandescent lamps in prismatic reflectors give uniform illumination of 30 footcandles at bench height.

TABLE II

Classification	Approximate Distribution of Luminaire Output	
	Upward	Downward
Direct	0–10%	90–100%
Semi-direct	10–40	60–90
General diffuse	40–60	40–60
Semi-indirect	60–90	10–40
Indirect	90–100	0–10

Direct Lighting

Industrial lighting (Figs. 19, 20, 21) is usually of the direct type. This can be defined as a lighting system in which practically all (90 to 100 per cent) of the light of the luminaires is directed downward, *i.e.*, directly toward the usual working areas. While in general such systems provide illumination on the working surfaces most efficiently, this may be at the expense of other factors. For example, disturbing shadows may result unless the area of the lighting units is relatively large or they are placed relatively close together. With incandescent lamp units, shadows are at a minimum when the area of the luminaires is largest, as with the so-called skylight or light-hood types. The relatively large size of the fluorescent lamps tends to minimize shadows, and this is especially true when they are installed in continuous rows.

Direct and reflected glare may be distressing. Care should be taken to install the equipment to avoid exposing the workers' eyes to the glare from brilliant sources or excessive contrasts between the light source and its background.

There are two different types of equipment usually classified under this heading—distributing types and concentrating types. The *distributing types* comprise porcelain-enameled reflectors and diffusers and units with the various white baked-enamel and synthetic finishes. The widespread distribution of light can also be obtained with proper finish, contour and configuration with aluminum, mirrored-glass, prismatic-glass, and similar finishes. This type of light distribution is advantageous in many industrial applications, for a large proportion of the seeing tasks in industry involves the viewing of surfaces that are vertical or nearly so.

In general, distributing units provide adequately uniform illumination when they are spaced a distance approximately equal to the mounting height above the floor, exceptions being structures of high ceilings or high bays. The shielding angle (a term used for fluorescent equipment) of the entire light source (Fig. 24-B) should not be less than 13 degrees below the hori-

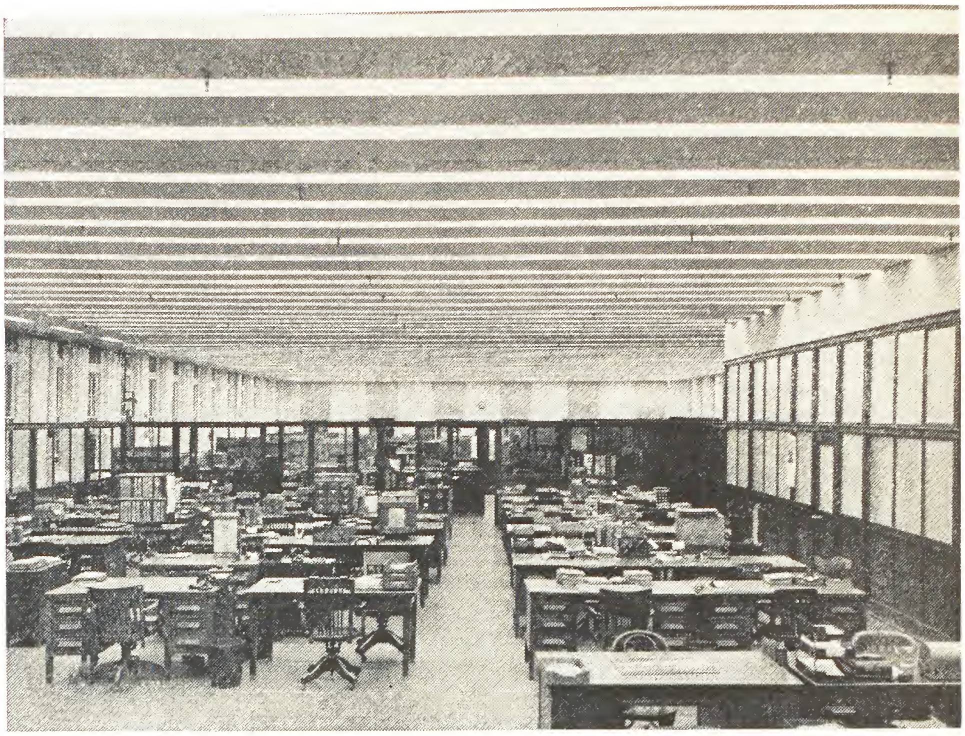


Fig. 22—The engineering and drafting areas of a room approximately 60 feet wide and 190 feet long. Fluorescent lamps in continuous troffers on 3-foot centers, inserted into a sound-proof ceiling give 70 footcandles of practically shadowless daylight effect in these areas. The trough has a 45-degree shielding angle. Vertical louvers are spaced one foot apart in a continuous row.

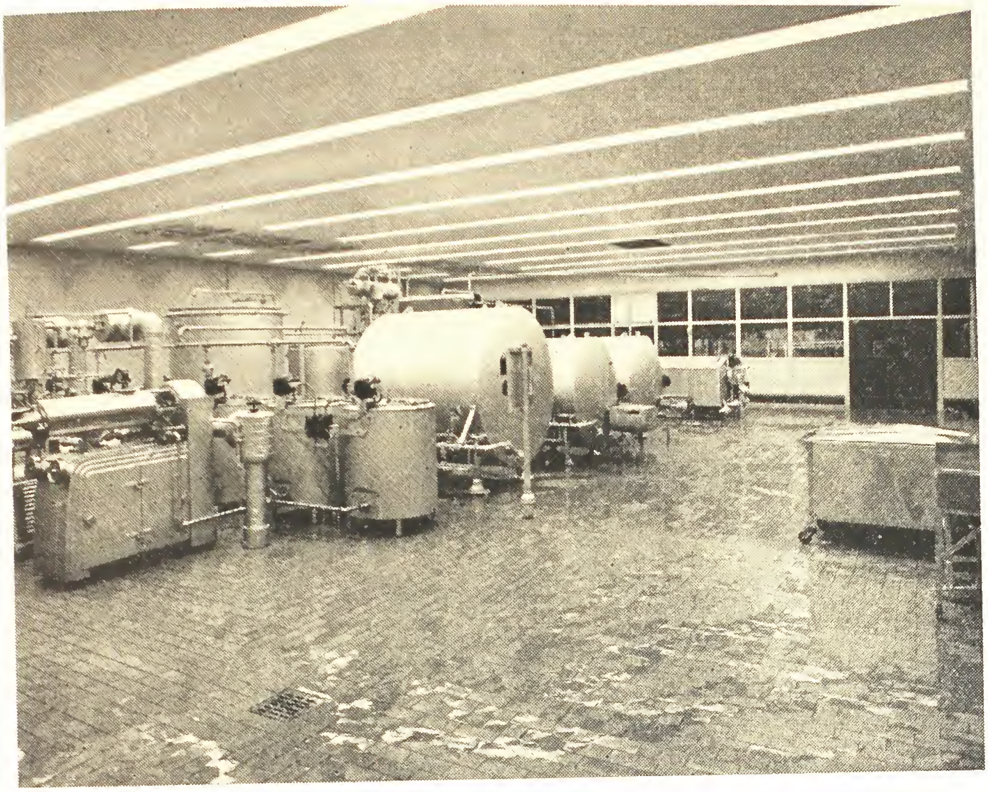


FIG. 23—General lighting (direct). Ice Cream Factory. Continuous troffers with single row of 48-inch fluorescent lamps. Spacing, 6 feet. Ceiling height, 12 feet. Illumination, 40 footcandles.

zontal, and a somewhat greater amount of shielding angle is desirable for filament lamp equipment (Fig. 24-A). The term *angle of cutoff* is used for filament lamp equipment, and the angle is measured from the vertical.

Among the *concentrating* direct lighting units are the prismatic and mirrored-glass and aluminum reflectors. These are most effectively used in

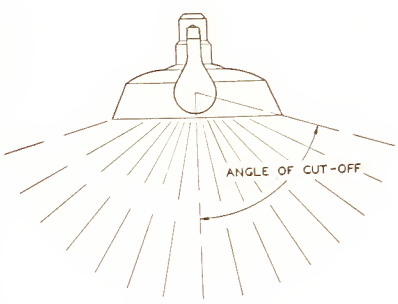


FIG. 24-A

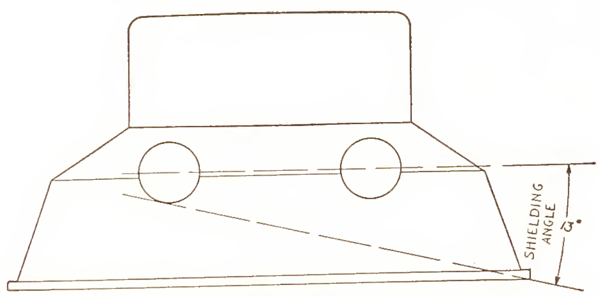


FIG. 24-B

FIG. 24-A—(View of Filament Reflector). With incandescent-lamp reflectors the angle of *cutoff* is measured from the center of the lamp bulb.

FIG. 24-B—(View of Fluorescent Reflector). With fluorescent-lamp reflectors the term *shielding angle* is used. It is measured from the extreme edge of the bulb, and is the angle at which complete shielding is obtained. (For this particular reflector the shielding angle is 13 degrees.)

narrow high bays and craneways where it is necessary to mount the reflector at a height as great or greater than the width of the area to be illuminated. (Fig. 19) In this case, a concentrated beam is necessary in order to get the light to the working area without excessive loss on the walls and windows. Spacing should be such as to provide uniform illumination over the working area. Such units are also frequently used in smaller sizes, some equipped with louvers for the supplementary lighting of specific work areas.

Semi-Direct Lighting

In this classification, 60 to 90 per cent of the output of the luminaire is directed downward to the working surface. There is then some contribution to the illumination at the working plane from light which is directed upward and reflected downward by the ceiling and upper wall areas. For the most part, luminaires in this class are of the open-bottom type, though some have closed bottoms of glass or plastic material. They are quite suitable for such areas as corridors, stairways, washrooms, and locker rooms.

General Diffuse Lighting

This classification refers to systems where the predominant illumination on horizontal working surfaces comes directly from the lighting units but where there is also a considerable contribution from upward light reflected back from ceiling and upper wall areas. Luminaires of this type are frequently found in factory offices.

One type of unit of this classification is the glass, diffusing, enclosing globe. (Fig. 25) Diffusing globes should be of sufficient density to conceal completely the lamp within. If diffusing globes are used to provide the higher illuminations of Table I, they are likely to become too bright from the standpoint of both direct and reflected glare unless a very considerable area of surface is provided.

Another general type of unit in this classification is represented by the so-called louvered units, sometimes termed "direct-indirect" by which from 40 to 60 per cent of the light emitted is directed upward and the remainder downward, but with little or no light directed toward the sides.

While general diffuse lighting systems give more illumination for a specified wattage than do indirect or semi-indirect systems, shadows are more noticeable, and some difficulty may be experienced with both direct and reflected glare.

Semi-Indirect Lighting

Semi-indirect lighting is defined as any system in which 60 to 90 per cent of the luminaire output is emitted upward toward the ceiling and upper side walls, while the rest is directed downward. (Fig. 26) Because the

Fig. 25—Glass, diffusing, enclosing globes.

Fig. 26—Semi-indirect.

FIG. 27—Indirect lighting. 500-watt incandescent lamps in indirect fixtures spaced on 9 by 9-foot centers. Ceiling height, 8 feet. Illumination, 30 footcandles.

ceiling constitutes an important part of such a lighting system, careful attention must be paid to having it as light in color as possible and to maintaining it in a good condition. In general, semi-indirect units give a little more light for the same wattage than do indirect units, but more attention must be given to the factors of direct and reflected glare. Luminaires of this classification are available in completely enclosed types, which resist the collection of dust and dirt and are easily cleaned. There are also styles that are open both top and bottom so that there remains only the upper surface of the lamps to collect dust and dirt.

Indirect Lighting

As the name implies, 90 to 100 per cent of the light from the luminaires is first directed to the ceiling and upper walls from which it is reflected diffusely to all parts of the room. (Fig. 27) In effect, the entire ceiling and high walls become a light source. With such a large area serving as a source of light, little direct glare is experienced. Shadows are practically eliminated and reflected glare reduced. With many polished metal pieces, a maximum visibility is obtained of such things as ruled lines, figures, mars or blemishes which are seen against the polished background. However, because the ceiling constitutes an important part of such a lighting system,

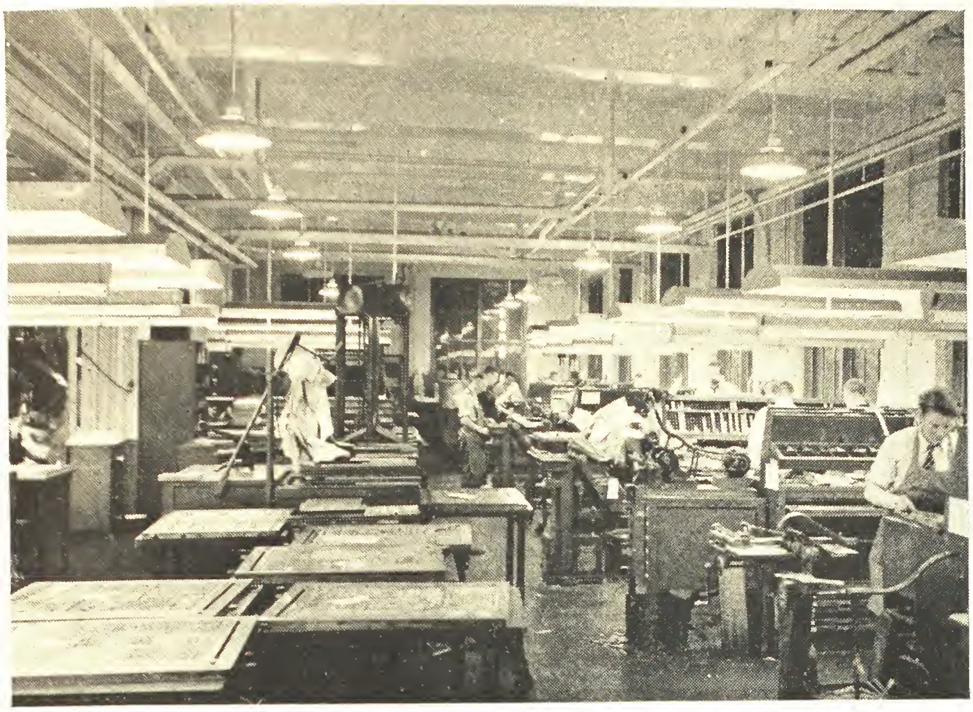


Fig. 28—Good general illumination in the type-setting and composing room is supplemented by large-area, low-brightness luminaires. Type faces are clearly visible and eyestrain from reflected glare is minimized. Illumination, 40 footcandles.

careful attention must be paid to having it as light in color as possible and maintaining it in good condition. It should be given a flat white finish having a high reflection-factor. Recently there have been developed specially-configurated ceilings with semi-matte finish that are designed to present reduced brightness at the angles at which they are normally seen.

The lighting units, which may have either opaque or luminous bottoms, should be such that they can be easily cleaned because a layer of dust and dirt absorbs a large amount of light.

This quality of lighting is highly desirable for such visual tasks as are found in drafting rooms, general and private offices.

Large-area sources of low uniform brightness approximate indirect lighting in effect. One measure of the quality of lighting which a given source will produce is the angle subtended by the source at the point of work.* With three-dimensional work tasks, particularly of a specular or semi-specular nature, this factor is of much importance. The most common large-area source is an indirect lighting system. However, there are many locations in industry where indirect lighting is impractical; for such cases there are available types of units which produce somewhat the same lighting effect. They consist of large luminous areas placed relatively close to the

* See references numbers 19 and 32 in Bibliography at end of this report.

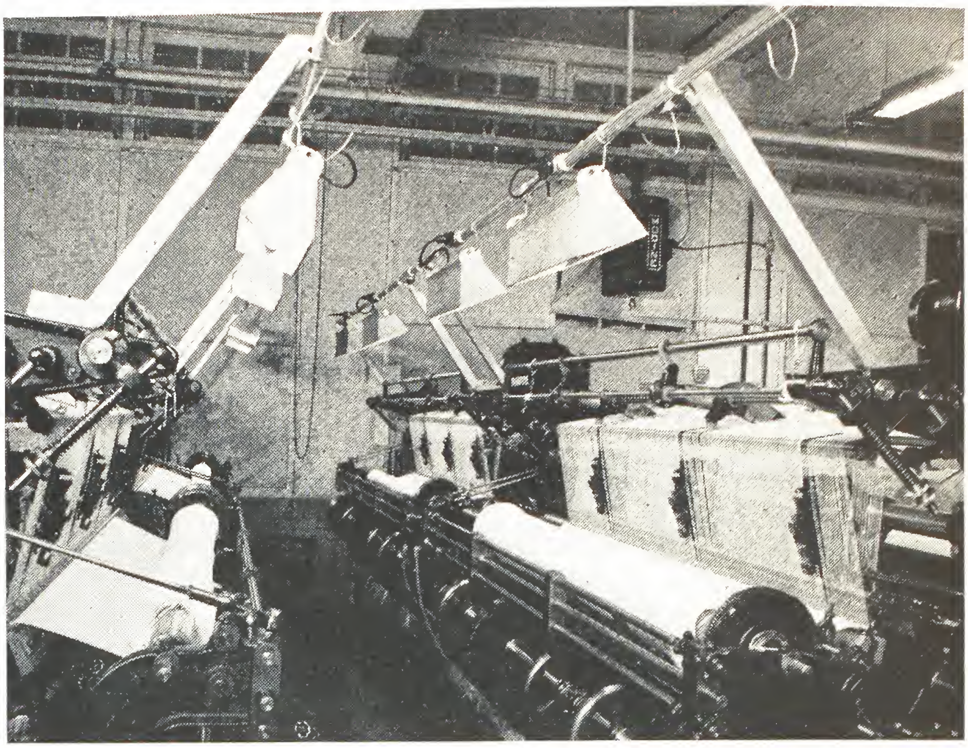


Fig. 29—Lighting specially arranged for silk mill looms, in effect supplementary lighting. Concentrating industrial units, mounted three feet above the work. One 24-inch fluorescent lamp per unit. Illumination on the work, 48 footcandles.

point of work. (Fig. 29) In this way, the subtended angle is of the same order of magnitude as a ceiling lighted with indirect units. For many locations throughout the actual working areas, such large-area sources are recommended. They are also effective for some office applications.

SUPPLEMENTARY LIGHTING

Supplementary lighting is necessary where the seeing task requires more light than is provided by the general illumination or where directional light is indicated.

Supplementary lighting (Figs. 3, 28, 29, 30) should be specifically designed for the particular visual task. A number of specially-designed luminaires are available which supplement the general lighting over a limited area. In this way, the light is confined to the immediate work area and does not become a source of glare to any one in the room. Where a diffusing source of low brightness is needed, a large-area, low-brightness unit can be placed directly over the work zone.

It is often preferable for concentrating supplementary lighting units to be mounted at some distance from the point of work. Thus, they cannot easily get out of adjustment and are not in the way of the workmen. This also eliminates the heat problem when filament lamps are used. Where a

Fig. 30—General Lighting:—Continuous rows of industrial reflectors. Each reflector has two 48-inch fluorescent lamps. Spacing between rows, 10 feet, 8 inches; mounting height, 10 feet, 6 inches. General illumination, 40 footcandles. Supplementary Lighting, one 36-inch fluorescent unit per operator. Illumination on the work, 250 footcandles.

certain degree of adjustment is desirable, units can be mounted on flexible arms for manipulation by the workman to obtain the maximum advantage.

Supplementary lighting, however, should be specifically designed for the particular visual task. High illumination is usually provided with supplementary lighting, and care should be taken that the contrast between the bright work and darker surroundings is not too great. In some cases, the reverse must be guarded against—that is, having high brightnesses elsewhere in the field of vision. Though no two sets of conditions are exactly alike, in general, the brightness ratio from maximum to minimum should not exceed 10 to 1; a ratio of 5 to 1 is preferable. While the measurement of *footcandles* is not an accurate determination of brightnesses, it suffices in most cases for this matter of satisfactory contrast; hence the common statement that with supplementary lighting the ratio of maximum to minimum footcandles should not exceed 10 to 1.

WINDOWLESS BUILDINGS

Inasmuch as natural light can not be relied upon, this new type of industrial plant should be provided with general illumination sufficient in intensity for the most critical seeing task. Each employee is now accustomed

to taking his unusually fine work to a window. This procedure will be impossible in windowless buildings. Therefore, a high level of good illumination must be installed for all regular operations, with supplementary lighting only where it is necessary to illuminate machines of an unusual shape.

An emergency lighting system is of particular importance in a windowless building.

ADEQUATE ELECTRICAL WIRING

In considering lighting, it must be realized that its achievement is dependent on the wiring which carries the necessary electrical energy.

In most communities, the installation of electric wiring is governed by local ordinances. While these are not uniform everywhere, they have much in common since practically all of them are based on the National Electrical Code,[28] a standard of the American Standards Association, compiled by municipal, federal government, utility, manufacturers, insurance, contractor and similar groups, including the professional societies. The essential function of the Code is to provide safety, from the viewpoint of *fire damages and personal hazards*. It should *not* be used as a criterion of efficient wiring; an inadequate wiring installation from the standpoint of lighting might be installed in a safe and workmanlike manner and, thus, conform with all the requirements of the Code.

As a guide to adequate wiring, the "Handbook of Interior Wiring Design,"[29] has been prepared by a committee consisting of representatives from a number of organizations, including the Illuminating Engineering Society. This Handbook is generally accepted as a sound approach to the fundamentals of achieving satisfactory performance of any lighting system, such as (1) economy, (2) voltage, (3) power factor, (4) flexibility and (5) adequacy.

The provisions of such manuals as the "Handbook of Interior Wiring Design" are intended primarily for ordinary Industrial Interiors. There are, however, many special kinds of buildings or structures, such as those of the Iron and Steel Industry, in which due to conditions peculiar to the industry, special wiring methods are found necessary.

1. *Economy.*

Wiring should provide for economical distribution of electrical energy. Every conductor of electricity resists, to a certain degree, the free flow *of*

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[28] National Electrical Code, National Board of Fire Underwriters, 85 John Street, New York City. 222 West Adams Street Chicago, Ill. Merchants Exchange Bldg., San Francisco, Calif.

[29] Handbook of Interior Wiring Design, Industry Committee on Interior Wiring Design, Room 2650, 420 Lexington Ave., New York City (also available from the headquarters' office of any sponsoring organization).

energy, thus causing waste. Large sizes of copper wire are the best protection against this waste, but since there is an economic limit based on initial and maintenance costs, a careful balance between waste and costs must be set.

2. *Voltage.*

Satisfactory voltage conditions must be maintained. In addition to the loss of energy, resistance and reactance cause a direct loss by lessening the voltage delivered at any utilization point. Since all energy-consuming devices are designed for particular operating voltages, failure to achieve this voltage may seriously affect the efficient performance of the device. Both filament and electric discharge lamps are quite sensitive to improper voltages. The filament lamps are more sensitive to light output with varying voltage conditions than the electric discharge lamps. However, the over-all performance of the electric discharge lamps is much improved both in light output and life when proper voltage is used.

3. *Power Factor*

The electric discharge lamp which produces light by means of an arc has an inherent low power factor. To the consumer, low power factor, by virtue of the added current drawn under this condition, means a waste of electrical energy in the form of heat or the necessity of adding additional copper to take care of the higher current involved. In addition, many electrical utilities have found it necessary to include power factor adjustments in their rate schedules. It is obvious that best economy can be obtained by the consumer demanding high power-factor control equipment.

4. *Flexibility*

Wiring installations must be flexible enough to allow for vital changes in utilization. Areas considered in original plans as warehouses may be converted to manufacturing areas; changes in processes might entirely alter the type of lighting most suitable; inspection demands may be increased. While no industrial wiring system can be designed to meet all possible changes, there are certain fundamentals of flexibility which should be incorporated.

Wiring installations should be of sufficient capacity to take care of reasonable future requirements. The trend in the use of electricity for all applications is steadily upward. Since wiring is distinctly a fixed element of building construction, allowance for future growth is mandatory.

5. *Adequacy*

Local ordinances, in general, consider wiring only from the safety standpoint with no thought for adequacy from the lighting standpoint. The

following summary is given as indicative of approved design practice for ordinary industrial interiors.

Branch Circuits

The number of lighting branch circuits required for a given area is determined by the average loading per square foot, which is based on standards of illumination for various processes. The overcurrent protection for branch circuits is assumed as 15 amperes, and it is stated that the initial load in any lighting branch circuit should not exceed 1000 watts, thus allowing for increased loading after installation. The minimum wire size is No. 12, with larger wire recommended for runs where the distance from the panelboard to the first outlet exceeds 50 feet. For heavy-duty lamp circuits the load per circuit should not exceed 1500 watts for No. 10 wire, 2500 watts for No. 8, and 3000 watts for No. 6.

The number of convenience outlets included on one branch circuit depends entirely on conditions, but where no knowledge of conditions is available, should be limited to six for manufacturing and ten for storage areas, with at least one such outlet in every bay. Convenience outlets for small power loads or extension light cords should be on separate circuits than those used for general lighting.

The minimum wire size for convenience outlet branch circuits should be No. 12, with the exception that a minimum of No. 10 should be used if the run to the first outlet from panelboard exceeds 100 feet.

Panelboards

At least one panelboard should be installed on each active floor.

On each panelboard there should be approximately one spare circuit position for every five circuits of the initial installation.

If possible, panelboards should be so located that branch circuit runs to first outlets should not exceed 100 feet.

Panelboards should always be easily accessible for the control of the lighting system and also for the replacement of fuses or the resetting of circuit breakers.

Feeders

The feeder sizes should be based on the number of branch circuits supplied, assuming 1000-watt load for each lighting and convenience outlet branch circuit, 500 watts for each spare circuit, and the actual load for any special circuit. To the total, such demand factors as permitted by the National Electrical Code or the local ordinance may be applied.

Provision for future growth should be made by the installation of oversize raceways for additional feeders, or by oversized feeders. This latter method (allowing 50 per cent extra capacity) is always recommended for

smaller installations where the ultimate wire size would be no greater than No. 4.

Switches

The switches which turn on and off the light in entrances and halls of buildings should be located near the point of entrance or exit. Likewise a switch which controls at least one circuit of lamps in a room should be located near each principal point of entrance when there are several.

In locating switches or control devices in factory and mill aisles, care should be exercised to arrange them systematically. This plan materially simplifies the finding of switches or control devices by those responsible for turning on and off the light.

For control purposes, groups of lamps may constitute a square or row parallel to the windows. The arrangement on a square has the advantage that any worker within the area gets the benefit of several nearby lighting units. An arrangement in rows parallel to the windows is desirable so that, when daylight fails, those workers farthest from the windows can have one or two rows lighted to supplement the natural light. With automatic photoelectric control this arrangement is ideal.

REWIRING

With the increased use of electricity required by higher lighting levels, by more intensive motor applications and by the new applications continually being developed, it is inevitable that the wiring capacities of existing buildings must sooner or later be increased. Formerly there was no alternative but to increase the raceway sizes (where wires are installed in conduit). With raceways buried in concrete slabs in fireproof construction this meant installing completely new conduit runs either on the surface or by channeling plaster and concrete.

Recent technical developments have made possible the manufacture of building wires with a reduced wall thickness of high-quality insulation. As a result, the overall diameters are reduced, so that more or larger conductors may be installed in existing raceways for rewiring purposes than was formerly possible.

Thus, capacities in existing raceways may be increased from 200 to 400 per cent depending upon specific conditions. The new conductors are available in four types of insulation with sizes up to 4/0; thus, they are suitable for feeder work as well as for branch circuit rewiring. The use of the new conductors greatly reduces rewiring costs from the old levels so that many proposed installations which formerly were prohibitive in cost are now economically practicable.

Wiring capacities may also be increased by changing the type of distribution system in use. A change from 2-wire, 115-volt to 3-wire, 115/230-volt results in a 100 per cent increase in capacity by addition of one conductor. A change from 3-wire single-phase to 4-wire 3-phase results in a correspondingly large increase by the addition of one wire. In many cases of building rewiring, it will be necessary to utilize both a change in the type of system as well as installation of conductors with reduced wall-thickness insulation to arrive at the desired new capacities economically.

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PRINTED IN U. S. A.